Cartographic Visualisation of Data Measured by Field Harvesters

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Abstract. Yield is one of the primary concerns for farmers, as it is the basis for their income and, among other impacts, influences subsidies and taxes. Field harvesters equipped with sensors and a GNSS (Global Navigation Satellite System) receiver provide detailed and spatially localised values, where the measurements from such sensors need to be filtered and subject to further processing, including interpolation, for follow-up visualisation, analysis and interpretation. These data, their processing and their application are some of the aspects of the precision agriculture concept. This paper describes the individual steps of processing the data acquired by harvesters, which especially include the spatial filtering of these data and their interpolation. We also proposed a scheme that summarises cartographic visualisation methods for these data (final data, as well as data from different processing steps). Methods of processing and cartographic visualisation were verified in the example of the Pivovárka field (Rostěnice farm, Czech Republic). Both 2D and 3D cartographic visualisations were created. Future development of the proposed concept is discussed in the conclusions.

Keywords. Cartographic visualisation, filtration, harvester measurement, precision agriculture, yield map.

1. Introduction

The main goals of precision agriculture (or precision farming) are, in general, the minimisation of negative impacts on the environment on the one hand and the maximisation of economic profit on the other. Geospatial information is highly valuable for these purposes. Therefore, using geospatial data provided by remote sensing and Global Navigation Satellite Systems (GNSS), as well as through their synthesis and analysis, farmers can more precisely determine what inputs to put exactly where and in what quantities. Conventional farming assumes that each field is a homogeneous area. Alternatively, precision farming techniques count and rely on the heterogeneity of a plot, and it is defined in terms of so-called yield productivity zones that reveal areas with lower and higher yields. Thus, an important

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way to collect geospatial data within the scope of precision agriculture is by field harvesters with yield monitors. Yield monitoring typically consists of a mass flow sensor and a GNSS device for geo-referencing the harvesters' measurements. Therefore, such harvesters use a GNSS to create a yield map of the field being harvested. Data from field harvesters represent the most detailed, as well as the most credible source of yield information. These data on crop yield can be used to determine variable rate treatments.

In this study, we describe the individual steps of processing the data acquired by harvesters, which especially include the spatial filtering of these data and their interpolation. We proposed a scheme that summarises cartographic visualisation methods for these data, and these methods were verified using a case study.

2. Related research

The effectiveness of decision-making in precision agriculture can be improved by integrating current monitoring technologies with Geographic Information System (GIS), GNSS and sensors. These technologies allow connection to the inner sphere of our spatial cognition via direct interaction with a new generation of cartographic visualizations. Cartography in its actual form is a unique instinctive multi-dimensional tool, which can be used in research, analyses, and communication of geospatial data (MacEachren, 1995).

The cartographic visualisation in precision agriculture is a topic that has not been extensively analysed and relatively too little is still known about how maps may be used effectively in this domain. Some papers (i.e. Kubíček et al., 2013; Štampach, Kubíček and Herman et al., 2015) deal with cartographic visualization of static sensors and their meteorological measurements. Charvát et al. (2018) describe visualization of yield productivity zones prediction derived from remote sensing data and agricultural machinery monitoring through interactive cartographic visualizations.

The papers that focus on the yield mapping from field harvesters data focus only on the issue of data processing in the GIS environment (Leroux et al., 2018; Zagórda and Walczykova, 2018). No existing articles or publications are directly concerned with the application of cartographic visualization to visualize this data.

Cartographic visualizations of this data are not covered by any reviewed papers or publications. Various cartographic visualisation methods are used in different steps of processing the data measured by field harvesters. These include exploration of the raw data (see section 3.1), their filtering (section 3.2), especially when using local filters, their selection and use of interpolation algorithms (section 3.3).

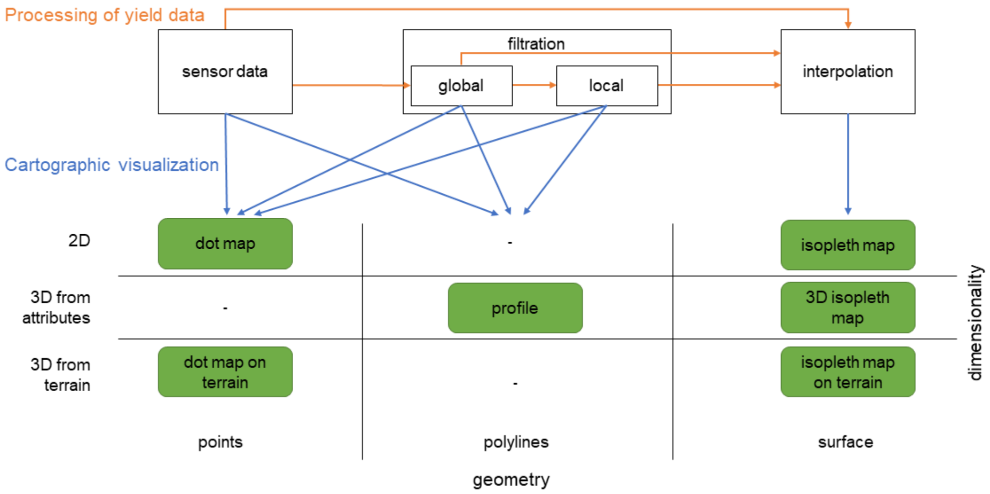

Figure 1. Overview of yield data processing and their cartographic visualization.

3. Materials and methods

This section describes the methodology of spatial data processing when creating cartographic visualisations of yield.

3.1. Sensors data

As mentioned above, the data measured by field harvesters represents the most detailed and credible source of yield information. Regardless, field harvesters provide measurements with some errors and inaccuracies. These biases in data corrupt the results, meaning, for example, that soil cannot be cultivated correctly. As suggested by Arslan and Colvin (2002) or Blackmore and Moore (1999), such errors might arise for the following reasons, for example, the occurrence of unexpected events during the harvesting process, leading to unusual behaviour on the part of the machine; the trajectory of the field harvester; and errors caused by incorrect calibration of the yield monitor.

3.2. Filtering of yield data

The main aim of data *filtration* is to remove the above-mentioned bias and refine the yield estimation. This issue was previously addressed, for example, by Gozdowski, Samborski and Dobers (2010); Spekken, Anselmi and Molin (2013); and Leroux et al. (2018). The processing of sensor data can be divided into two steps—global filtering and local filtering—as follows. Global filtering removes non-credible values within the whole dataset using the statistical analysis of measurement values and related attributes. Local filtering focuses afterwards on some parts of the dataset at a higher level of detail, and it is mostly based on the neighbourhood of data point values.

Global filtering uses statistical (non-spatial) methods for detecting non-credible yield values. Global filters detect incorrect outliers based on the range of possible yield values, the speed of a field harvester and the direction of harvesting. Meanwhile, *local filtering* handles the data in greater detail, and it is based on differences between neighbouring measurements or patterns. Local filtering brings the most precise results regarding domain knowledge, e.g. measurements, data processing and yield history, as well as knowledge of the data, the situation and of the problematics in general. Local filtering often comprises a set of subjective methods (points are excluded manually).

3.3. Interpolation

Continuous yield maps are created by different interpolation methods. The most commonly used methods include *Inverse Distance Weighting* (IDW), *Simple Kriging* and *Ordinary Kriging* (Souza et al., 2016). Continuous yield maps, in general, can be used for the comparison and evaluation of sensor measurements that were obtained directly from the field harvester and processed by global and local filters. Continuous yield maps can also be used in other analyses within precision farming, such as when comparing the measured yield with that predicted from yield productivity zones based on remote sensing.

4. Use case

Data acquisition was conducted in 2017 at the Pivovárka field, which is farmed by the Rostěnice cooperative farm (Czech Republic; N49.105 E16.882). Data were measured by a CASE IH AXIAL FLOW 9120 field harvester equipped with an AFS Pro 700 monitoring. The measurements were of Global Navigation System of Systems–Real-Time Kinematics (GNSS–RTK) quality, i.e. they provided a spatial resolution of less than 0.1 m. Measurements were taken continuously each second at an average speed of 1.55 m.s-1, which was recommended as optimal at the Rostěnice Farm for cereal harvesting by the above-mentioned field harvester.

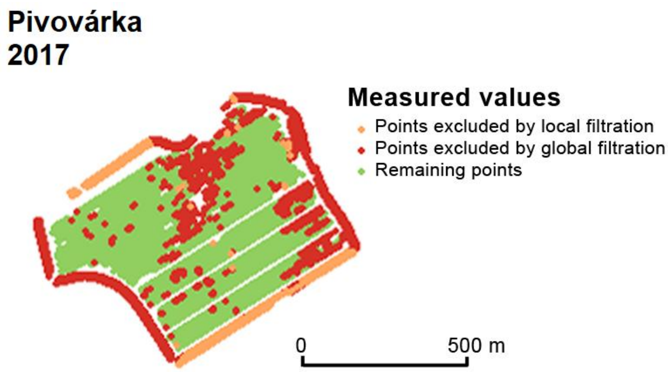

Figure 2. Dot maps depicting excluded and remaining points during filtration.

The data were first filtered through so-called global filters and then by local filters (see Figure 2). The results of both filtration steps were analysed and compared with each other and with measured (raw) data (see Figure 3). For interpolation, the Simple Kriging method was used, because the measured values had normal distributions, were stationary and did not show any significant trends, so the preconditions were met. The parameters of the interpolations of each model were computed utilizing the Exploratory Spatial Data Analysis in the ArcGIS 10.6 software.

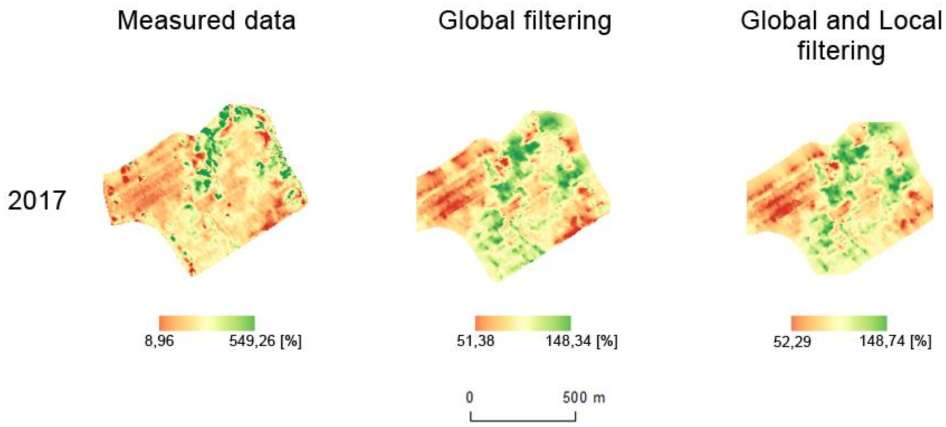

Figure 3. Isopleth maps generated from different stages of data processing.

Figure 4 shows the role of topography. A narrow valley is an area with significantly higher yields than the average of the field. The conducted measurements showed that yields in such a narrow valley within a field might reach more than 150% of the average for the whole field.

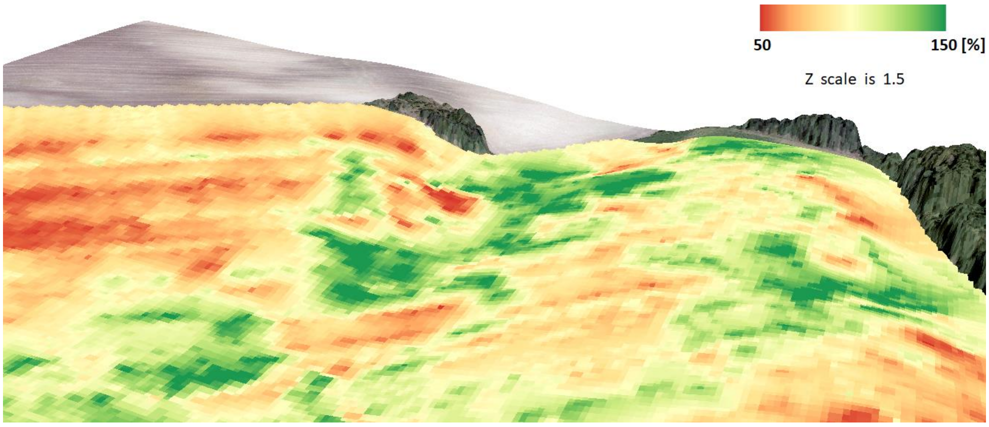

Figure 4. Isopleth map of the measurements processed by global and local filtering for the Pivovárka field in 2017 and draped on the digital terrain model.

5. Discussion

For the depiction of yield maps, 3D visualisation is particularly suitable, because it primarily enables the understanding of the relationship between topography and yield values and patterns. Other benefits of 3D visualisation, as summarised by Shepherd (2008), such as more space for displaying additional data variables and a more familiar view of spaces, also apply here. The third dimension (the Z-axis) can represent altitude (yield data are then displayed on the digital terrain model as texture), or it can show the distribution of values for a particular attribute (in this case yield values). Benefits of 3D visualization of yield data briefly mentioned only Charvát et al. (2018).

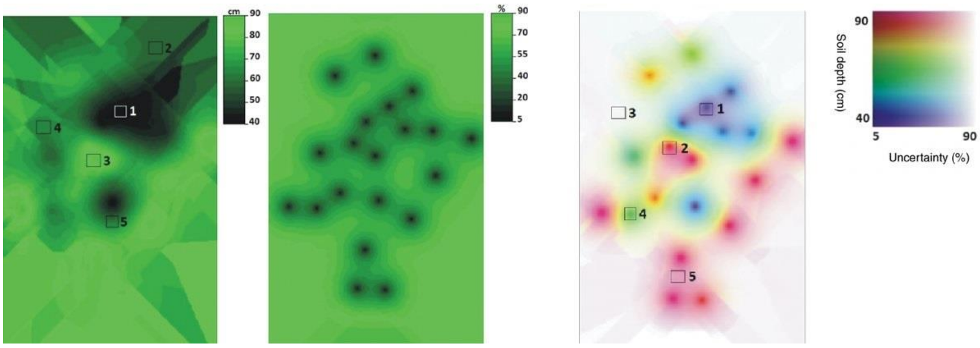

Figure 5. Examples pair of maps compared (left) and bivariate colour scale (right). Source: Kubíček and Šašinka (2011).

Uncertainty is another of potentially critical factors of yield data visualization, which is not addressed in previous studies. Approach, which was originally proposed for visualization of soil sampling data and tested on users by Kubíček and Šašinka (2011), can be transferred also on yield data. Both bivariate colour scales and pair of maps can be used for this purpose (see Figure 5), however, verifying which of these methods is more suitable for visualizations of yield data and uncertainty in these data may be the subject of further research

6. Conclusions and future work

Various methods of cartographic visualisation are important in the processing and interpretation of yield data, and in precision agriculture in general. This paper illustrates the use of cartographic visualisation to filter and present detailed geospatial yield data. Examples of different types of cartographic visualisation were created from data measured by a harvester in the Pivovárka field.

Future work will follow three directions: an extension of the described approach to different fields and data from different harvests; an application of these data and visualisations in more complex analysis (both machine processing and visual analysis); and, finally, user evaluation of designed visualisations and their variants.

Regarding usability research, different aspects of cartographic visualisation should be examined. These aspects in the case of 3D visualisations include, for example, the level of interactivity of visualisations (static perspective views versus interactive visualisations), the effect of different Z scales or different colour schemes in general.

Future usability research focusing on yield maps and related cartographic visualizations is very important because it is obvious that these cartographic visualizations must be not only legible but also understandable also for readers that are experts in their specialisation, in this case for agronomist or farmers.

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